

## DEVICE AND METHODS OF MEASURING PRESSURE

### CROSS REFERENCE RELATED APPLICATION INFORMATION

- 5        This application claims priority from United States Provisional Patent Application No. 60/550,694, filed March 5, 2004. The contents of these applications are incorporated herein by reference.

### FIELD OF THE INVENTION

- 10      This invention relates to pumps and methods of measuring pressure within a pump chamber.

### BACKGROUND OF THE INVENTION

- It is desirable to measure the pressure inside a pump chamber. In some fields, pumps  
15      have decreased in size such that the placement of stress gauges on the housing of the pump has become difficult. For example, for pumps used in liquid chromatography it is desirable to operate at pressures greater than 3,000 pounds per square inch (psi). This pressure represents the normal upper limit of conventional chromatographic apparatus. Pressures in the ultra pressure region of greater than 4,000 up to 12,000 psi  
20      are desired. To attain these high pressures pump chambers are machined with greater precision. There is less area in the pump chamber to receive connections to pressure sensors.

### SUMMARY OF THE INVENTION

- 25      Embodiments of the present invention are directed to method and devices for measuring the pressure of a pump chamber in which no internal opening or connections are needed. One embodiment of the present invention is directed to an apparatus for pumping fluid. The apparatus comprises at least one housing. The housing has an exterior surface and an interior surface. The interior surface defines a  
30      chamber for receiving a plunger and having a fluid input opening and a fluid discharge opening extending between said interior and exterior surfaces. The chamber has a cylindrical shape with a first end wall and a plunger opening for receiving a plunger. The exterior surface of the housing has a transducer surface

surface define a first thickness and a second thickness. The transducer surface has the second thickness exhibiting measurable deformation upon the chamber holding a fluid under pressure such that the transducer surface having a first position at which the chamber is at one pressure and a second position at which the chamber is at a second pressure. A plunger is received in the plunger opening for reciprocating movement in the chamber. The reciprocating movement causing fluid movement, to enter the chamber through the fluid input opening and out through the fluid discharge opening. At least one strain sensor is affixed to the transducer surface. The strain sensor producing at least one signal upon the transducer surface assuming the first position and at least one signal upon the transducer surface assuming the second position to function as an integrated pressure transducer.

Preferably, the transducer surface is a flat surface capable of deformation upon pressurization of said chamber.

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Preferably, the housing has a composition selected from the metals and metal alloys consisting of titanium, aluminum, and vanadium. A most preferred metal and metal alloy is titanium, aluminum and vanadium alloy, 6Al4V.

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Preferably, the exterior surface of the housing has a cylindrical portion and a half cylindrical portion. The cylindrical portion forms a base for attachment to other apparatus. Such other apparatus normally would consist of pump motors and supporting structure for holding the pump within a frame or further housing. The half cylindrical portion has a flat planar surface and a half cylindrical surface. The half cylindrical portion and the cylindrical portion can also be made as separate units and joined into a unitary structure. The two separate pieces can be made of different materials. It is useful to make the unit or portion having the transducer surface of the titanium alloy. For cost considerations, it may be useful to make the base unit of stainless steel.

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Preferably, the transducer surface is a bottom surface of a cavity in said flat planar surface. That is a, a cavity is machined into the flat surface to provide a transducer surface. The cavity provides a second thickness, the thickness subject to deformation, of approximately 0.10 to 0.001 inches, more preferred, approximately 0.05 to 0.005

inches, and, more preferred, 0.040 to 0.01 inches. In one preferred embodiment, the cavity provides a second thickness of .029 plus or minus .001 inches.

5 Circuits and the like which amplify the signal of the strain sensor are preferably mounted on the flat planar surface. The circuits and strain sensor are preferably covered by a cover for protection.

A further embodiment of the present invention is directed to a method of measuring pressure in a pump chamber. The method comprises the steps of providing  
10 at least one housing having an exterior surface and an interior surface. The interior surface defines a chamber for receiving a plunger. The housing further has a fluid input opening and a fluid discharge opening extending between said interior and exterior surfaces. The chamber having a cylindrical shape with a first end wall and a second end wall. At least one end wall has a plunger opening for receiving a plunger.  
15 The exterior surface of the housing has a transducer surface between the first end wall and the second end wall. The interior surface and exterior surface define a first thickness and a second thickness. The transducer surface having the second thickness and exhibiting measurable deformation upon the chamber holding a fluid under pressure such that the transducer surface has a first position at which the chamber is at  
20 one pressure and a second position at which said chamber is a second pressure. A plunger is received in the plunger opening for reciprocating movement in the chamber. The reciprocating movement causing fluid movement to enter the chamber through the fluid input opening and out through the fluid discharge opening. At least one strain sensor is affixed to the transducer surface, The strain sensor produces at  
25 least one signal upon said transducer surface assuming the first position and at least one signal upon the transducer surface assuming the second position to function as a integrated pressure transducer. The method further comprising the step of taking readings of the strain sensor as an indication of pressure in the chamber.

30 These and other features and advantages will be apparent upon reading the following detailed description of the invention and viewing the drawing.

### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 depicts in cross section a side view of an apparatus embodying features of  
5 the present invention;

Figure 2 depicts in cross section, an end view of an apparatus embodying features of  
the present invention;

10 Figure 3 depicts in top view, an apparatus embodying feature of the present invention.

### DETAILED DESCRIPTION OF THE INVENTION

The present invention will be described as a method and device for measuring the  
pressure of a pump chamber in which no internal opening or connections are needed.  
15 The invention has special application to pumps used in chromatography and chemical  
analysis. However, individuals skilled in the art will recognize that the present  
invention has applications in other fields as well. Individuals skilled in the art will  
further recognize that the present invention is subject modifications and alterations  
without deviating from the overall teaching of the present discussion which by way of  
20 example, without limitation discloses one or more preferred embodiments.

Turning now to Figure 1, an apparatus, generally designated by the numeral 11, is  
depicted. Apparatus 11 is for pumping fluid. Apparatus 11 comprises at least one  
housing 13, a plunger 15 and a strain sensor 17.  
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Housing 13 has an exterior surface 21 and an interior surface 23. The interior surface  
defines a chamber 25 for receiving the plunger 15. A fluid input opening 29 and a  
fluid discharge opening (not shown) extends between said interior surface 23 and  
exterior surfaces 21. A check valve 33 is depicted in communication with the fluid  
30 input opening 29. The fluid outlet opening would normally have fittings for  
communication with other assemblies and conduits in a manner well known in the art.

The chamber 25 has a cylindrical shape with a first end wall 31 and a plunger opening  
35 for receiving plunger 15. Individuals skilled in the art will recognize that the

chamber may deviate from a perfect cylinder and encompass forms with one or more sides while retaining the function of cooperation with the plunger 15. Plunger 15 is received in the plunger opening 35 for reciprocating movement in the chamber 25.

The reciprocating movement causes fluid movement. Fluid enters the chamber  
5 through the fluid input opening 29 and out through the fluid discharge opening (not shown).

The exterior surface 21 of housing 13 has a transducer surface 41 between the first end wall 31 and plunger opening 35. The interior surface 23 and exterior surface 21  
10 define a first thickness and a second thickness. The first thickness is for structural integrity and minimal elasticity. The second thickness exhibits deformation upon pressure induced stress. The transducer surface 41 has a second thickness exhibiting measurable deformation upon the chamber 25 holding a fluid under pressure. That is, the transducer surface 41 has a first position at which the chamber is at one pressure  
15 and a second position at which the chamber is at a second pressure. Strain sensor 17 is affixed to the transducer surface 41. Strain sensor 17 produces at least one signal upon the transducer surface assuming the first position and at least one signal upon the transducer surface assuming the second position to function as an integrated pressure transducer.

20 As depicted in Figure 2, the transducer surface is a flat surface capable of deformation upon pressurization of said chamber. However, curved or irregular surfaces can be used with appropriate strain sensors 17.

25 Housing 13 has a composition selected from the metals and metal alloys consisting of titanium, aluminum, and vanadium. A most preferred metal and metal alloy is titanium, aluminum and vanadium alloy, 6Al4V.

Preferably, the exterior surface 21 of housing 11 has a cylindrical portion 45 and a  
30 half cylindrical portion 47. The cylindrical portion 45 forms a base for attachment to other apparatus (not shown). Such other apparatus normally would consist of pump motors and supporting structure for holding the pump within a frame or further housing.



As best seen in Figures 2 and 3, the half cylindrical portion 47 has a flat planar surface 51 and a half cylindrical surface 53. As used herein, the term "half" is used to mean part cylindrical and not a precise division. Turning now to Figures 1 and 2, the half cylindrical portion 47 and the cylindrical portion 45 can also be made as separate units and joined into a unitary structure. The two separate pieces can be made of different materials. It is useful to make the unit or portion having the transducer surface of the titanium alloy. For cost considerations, it may be useful to make the base unit, that is the cylindrical portion 45 of stainless steel.

10 Preferably, the transducer surface 41 is a bottom surface of a cavity 55 in the flat planar surface 51. That is a, cavity 55 is machined into the flat surface to provide a transducer surface 41. The cavity 55 provides a second thickness, the thickness subject to deformation, of approximately 0.10 to 0.001 inches, more preferred, approximately 0.05 to 0.005 inches, and, more preferred, 0.040 to 0.01 inches. In one  
15 preferred embodiment, the cavity 55 provides a second thickness of .029 plus or minus .001 inches.

Circuits and the like which amplify the signal of the strain sensor 17 are incorporated on a circuit board 61 and mounted on the flat planar surface. The circuit board 61  
20 and strain sensor 17 are preferably covered by a cover 63 for protection.

A further embodiment of the present invention is directed to a method of measuring pressure in a pump chamber 25. The method comprises the steps of providing a housing 13 having an exterior surface 21 and an interior surface 23. The interior  
25 surface 23 defines a chamber 25 for receiving a plunger 15. The housing 13 further has a fluid input opening 29 and a fluid discharge opening (not shown) extending between said interior surface 23 and exterior surface 23. The chamber 25 has a cylindrical shape with a first end wall 31 and a plunger opening 35 for receiving plunger 15. The exterior surface 21 of the housing 13 has a transducer surface 41  
30 between the first end wall 31 and the plunger opening 35. The interior surface 21 and exterior surface 23 define a first thickness and a second thickness. The transducer surface 41 having the second thickness and exhibiting measurable deformation upon the chamber 25 holding a fluid under pressure such that the transducer surface 41 has a first position at which the chamber is at one pressure and a second position at which

said chamber 25 is a second pressure. A plunger 15 is received in the plunger opening 35 for reciprocating movement in the chamber 25. The reciprocating movement causes fluid movement. Fluid enters the chamber 25 through the fluid input opening 29 and out through the fluid discharge opening (not shown). At least  
5 one strain sensor 17 is affixed to the transducer surface 41. The strain sensor 17 produces at least one signal upon said transducer surface 41 assuming the first position and at least one signal upon the transducer surface 41 assuming the second position to function as a integrated pressure transducer. The method further comprising the step of taking readings of the strain sensor 17 as an indication of  
10 pressure in said chamber.

Thus, embodiments of the present invention and how to make and use the invention have been described with the understanding that the description is that of preferred embodiments subject to change and variation. And, the invention should not be so  
15 limited to such description but should encompass the subject matter of the following claims.